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Efficacy of zinc and iron nutrition on growth, yield, quality and economics of castor (Ricinus communis L.) under semi-arid environment

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ABSTRACT

A field experiment was carried out at CCS HAU, Regional Research Station, Bawal during the year 2022-23 and 2023-24 consisting of nine treatment combinations viz. RDF (T_1), RDF + 25 kg/ha Zinc Sulphate (21% zinc) as soil application at the time of sowing (T_2), RDF + 25 kg/ha Ferrous Sulphate (19% iron) as soil application at the time of sowing (T_3), RDF + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing (T_4), RDF + Foliar spray of 0.5% Ferrous Sulphate solution at 30 and 60 DAS (T_5), RDF + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_6), RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_7), RDF + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_8) and RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_9) laid out in randomized block design with three replications. Soil of the experimental site was sandy loam in texture low in N, P and medium in K, with slightly alkaline in reaction (pH – 7.9). The castor crop (hybrid ICH-66) was sown in second fortnight of July, 2022 and 2023 and harvested in the last week of March, 2023 and 2024 during both the years, respectively. Pooled data (2022-23 and 2023-24) reveal that zinc and iron either soil applied, foliar applied or both (alone or in combination) resulted in an increase in yield attributes and yield of castor. Treatment where 25 kg/ha Zinc Sulphate soil applied followed by foliar spray of 0.5% Ferrous Sulphate solution at 45 days after sowing recorded significantly higher seed yield in comparison to RDF and RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing. Oil content was not influenced by the treatments tested. All the treatments did not differ significantly among themselves in respect of available N, P and K in soil. Higher available Zn and Fe content was found under the treatments where iron and zinc either soil applied, foliar applied or both (alone or in combination) over RDF, respectively. Agronomic efficiency and partial factor productivity of Zn and Fe was highest (88.7 and 350 kg/kg, respectively) under RDF + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing.

Keywords: *Castor, zinc, iron, foliar spray, yield attributes, yield, economics and nutrient content.*

1. Introduction

India is the World leader in castor production and the sole exporter of castor oil, seed and some of its derivatives. Its yield is the most useful and economically important plant oil having vast and varied industrial applications such as lubricants, surfactants, surface coating, cosmetics, plasticizers, resins, paints, pharmaceuticals, adhesives, waxes, polishes, varnishes, perfumes, textile dyes, textile finishing agents, nylon etc. [10]. Globally, India holds the prime position in terms of area, production, and productivity of castor [7]. Currently, it is cultivated in an area of 0.83 million hectares; with a productivity of 2.30 t/ha, approximately 1.92 million tons of castor seed is being produced in India (ICAR-IIOR, 2021). However, wide regional disparities are encountered in yield of this crop, the lowest being 509 kg/ha in Andhra Pradesh. The low productivity of this crop was due to its cultivation in marginal and poor soil fertility conditions by the resource-poor farmers under uncertain rainfall conditions [8].

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Although irrigated regions contribute significantly to the overall production, the southern rainfed regions also possess substantial areas under castor cultivation [11]. Owing to its premium market price [16], modest production cost [11], climate resilience [24], and drought tolerance nature [15] castor appeals to small and marginal farmers to adopt it in their existing cropping systems. Continuous use of imbalanced and inadequate dose of fertilizers can have adverse effect on crop productivity and soil health on a long-term basis [6]. Castor is a long-duration crop (180–210 days), the fertilizers applied during sowing may not remain sufficiently available for the rest of its critical stages, especially during maximum source development and subsequent reproductive stages. In castor, the highest nutrient demand occurs during the flowering and reproductive phases [14]. Balanced nutrient management in crops is of utmost importance for several reasons, as it directly affects crop health, productivity, and environmental sustainability. Balanced nutrient management can improve crop resilience to climate change effects like biotic and abiotic stresses. Currently, the recommended fertilizer for castor crop comprises only the primary nutrients, namely nitrogen, phosphorus and potassium. The Zn and S deficiency is holding back the potentiality of rainfed farming in arid and semi-arid tracts of India [22]. Hence, it is imperative to incorporate Zn and S into the nutrient management framework. Keeping in view the present investigation attempts to study the efficacy of zinc and iron nutrition on growth and yield of castor under semi-arid environment.

2. Materials and Methods

2.1 Experimental design and study material

A fixed plot field experiment was carried out at CCS Haryana Agricultural University, Regional Research Station, Bawal during 2022-23 and 2023-24 consisting of nine treatment combinations *viz.* RDF (T_1), RDF + 25 kg/ha Zinc Sulphate (21% zinc) as soil application at the time of sowing (T_2), RDF + 25 kg/ha Ferrous Sulphate (19% iron) as soil application at the time of sowing (T_3), RDF + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing (T_4), RDF + Foliar spray of 0.5% Ferrous Sulphate solution at 30 and 60 DAS (T_5), RDF + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_6), RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_7), RDF + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_8) and RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_9) laid out in randomized block design with three replications. The castor crop (hybrid ICH-66) was sown in the second fortnight of July, 2022 and 2023 and harvested in the last week of March, 2023 and 2024 during both years, respectively. The crop was fertilized with the recommended dose of fertilizers (120:60:30) N: P_2O_5: K_2O kg/ha. Recommended agronomic practices viz. seed soaking, seed treatment with fungicide (*carbendazim* @ 4 gm per kg seed) and bio-fertilizer (*Azotobactor* + P.S.B.) weed management, irrigation management and timely management of insect-pest and diseases were followed. Castor was sown at 150 cm x 90 cm spacing. The net plot size was 7.5 m x 7.2 m. After harvest, seed samples were collected for analysis of oil content. The oil content in castor seeds produced under various treatments was analyzed as per the method suggested by [23]. At the end of the cropping cycle, the soil samples (0-15 cm) were collected and analyzed for available N, P, K, Zn and Fe by adopting standard analytical methods [21]. Statistical analysis of the data was carried out using standard analysis of variance.

2.2 Experimental site and climatic conditions

Geographically, Bawal is located at 28.07 °N and 76.59°E in western Haryana. It is situated in agroclimatic zone II (semi-arid region) of Haryana. The soil of the experimental field was low in organic matter (0.20%) and available nitrogen (106 kg/ha) and medium in available phosphorus (11.6 kg/ha) and available potassium (137 kg/ha) with slightly alkaline in reaction (pH 7.9) at the initiation of the experiment. The total rainfall received during the crop season of 2022-23 and 2023-24 (July-March) was 801.3 and 784.8 mm with 60 and 46 numbers of days, respectively (Fig. 1). In this study, despite good crop growth yield level across the treatments in 2022-23 was slightly lower when compared to 2023–24. It was due to unexpected rainfall received during September. Lower temperature coupled with higher relative humidity favoured the incidence of capsule borer. Despite a prophylactic and curative spray of quinalphos 25% EC @ 4 ml per liter of water, a portion of yield was affected due to the incidence of capsule borer in 2022-23. While the crop enjoyed congenial weather throughout the crop growth in 2023-24 as a result yield levels were slightly higher.

2.3 Partial factor productivity (PFP) for zinc and iron under various treatments was calculated as per the methodology suggested by [4, 5] by using the following formula.

PFP (kg/ kg) = Grain yield (kg /ha) /Nutrients applied (kg /ha)

2.4 Agronomic efficiency (AE) was calculated by comparing different treatments with absolute control (no fertilizer) and was calculated as per the methodology suggested by [4, 5] by using the following formula.

Agronomic efficiency (kg/kg) = Seed yield in fertilized plot (kg/ha) - Seed yield with absolute control plot (kg /ha)/ Quantity of nutrients applied (kg /ha).

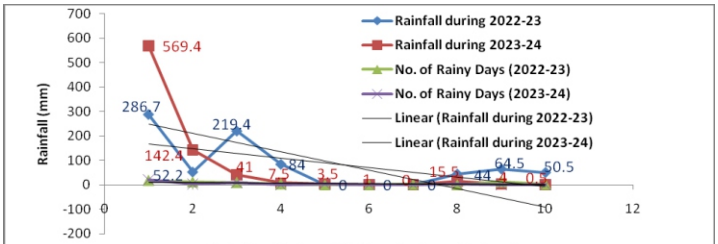

Fig. 1. Monthwise rainfall (mm) and no. of rainy days

3. Results and Discussion

3.1 Growth and yield attributes

The data on various growth and yield contributing characters viz. Plant height upto primary spike, number of nodes upto primary raceme, number of spikes per plant, number of capsules per primary spike and 100-seed weight influenced by various treatments are presented in Table 1. The perusal of pooled data of two years reveal that zinc and iron either soil applied, foliar applied or both (alone or in combination) increased growth and yield attributes of castor. The plant height, a number of nodes upto primary raceme and number of spikes per plant (78.73 cm, 21 and 11.7, respectively) were significantly higher under RDF + 25 kg/ha Zinc Sulphate (21% zinc) as soil application + Foliar spray of 0.5% Ferrous Sulphate (19% iron) solution at 45 DAS (T_8) over RDF (71.12, 18 and 6.7; respectively) and the treatments where there was alone soil application of Zinc Sulphate and Ferrous Sulphate at the time of sowing but remained at par with the treatments where either Zinc Sulphate or Ferrous Sulphate was applied in soil in combination with foliar application of Zinc Sulphate or Ferrous Sulphate. A number of capsules per primary spike (71.5) was significantly higher under RDF + 25 kg/ha Zinc Sulphate as soil application + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_8) over RDF (64.07) and the treatment where there was alone soil application of Ferrous Sulphate at the time of sowing (67.55) but remained at par with the treatment where there was alone soil application of Zinc Sulphate at the time of sowing and the treatments where either Zinc Sulphate or Ferrous Sulphate was applied in soil in combination with foliar application of Zinc Sulphate or Ferrous Sulphate. All the treatments did not differ significantly among themselves in respect of 100-seed weight (Table 1).

Table 1. Effect of zinc and iron nutrition on growth and yield attributes of castor (Pooled data of two years)

Treatments	Plant Height (cm) upto primary spike	No. of nodes upto primary raceme	No. of spikes/plant	No. of capsules/ primary spike	100- seed weight (g)
T_1: RDF	71.12	18	6.7	64.07	31.23
T_2: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing	72.13	19	8.7	70.27	31.61
T_3: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing	73.27	18	7.7	67.55	31.03
T_4: T1 + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing (DAS)	76.68	20	9.7	69.60	32.60
T_5: T1 + Foliar spray of 0.5% Ferrous Sulphate solution at 30 and 60 DAS	78.20	19	9.7	68.17	32.47
T_6: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	77.13	20	10.7	70.08	32.19
T_7: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	80.73	19	9.2	69.45	32.67
T_8: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	78.73	21	11.7	71.50	33.13
T_9: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	77.35	20	9.7	69.53	32.74
SEm±	1.07	0.61	0.9	1.26	0.68
CD (p=0.05)	2.29	2.0	2.8	3.66	NS

3.2 Yield, economics and quality

A quick view of data presented in Table 2 indicates that highest seed yield was recorded under the treatment where 25 kg/ha Zinc Sulphate soil applied followed by foliar spray of 0.5% Ferrous Sulphate solution at 45 days after sowing. This treatment recorded significantly higher seed yield (36.32 q/ha) in comparison to RDF (26.15 q/ha) and RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing alone (29.08 q/ha), which was 38.9 and 24.9 % higher than these treatments, respectively. However, all the treatments did not differ significantly among themselves in respect of seed yield where either Zinc Sulphate or Ferrous Sulphate was applied in soil in combination with foliar application of Zinc Sulphate or Ferrous Sulphate.

A thorough understanding of data in Table 2 reveals that highest Gross return (Rs. 174328), Net return (Rs. 119768) and B:C ratio (3.19) obtained highest was incurred under RDF + 25 kg/ha Zinc Sulphate as soil application + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS. Net return and B:C ratio was 65.6 and 35.2 % higher under RDF + 25 kg/ha Zinc Sulphate as soil application + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS over RDF (T_8). This might be due to increase in seed yield which contributed towards higher net return and B:C ratio. Oil content was not influenced by the treatments tested. However, oil content was numerically higher under treatments where either Zinc Sulphate or Ferrous Sulphate was applied in soil alone or in combination with foliar application of Zinc Sulphate or Ferrous Sulphate over RDF. Optimal levels of zinc and iron ensure efficient nutrient uptake and utilization, supporting vigorous growth and development and quality in sorghum crops (Table 2).

Table 2. Effect of zinc and iron nutrition on yield, economics and oil content of castor (Pooled data of two years)

Treatments	Seed yield (q/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio	Oil content (%)
T_1: RDF	26.15	125496	72306	2.36	47.17
T_2: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing	32.62	156592	102442	2.89	47.40
T_3: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing	29.08	139592	85042	2.56	47.68

T_4: T1 + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing (DAS)	33.96	163016	109076	3.02	47.95
T_5: T1 + Foliar spray of 0.5% Ferrous Sulphate solution at 30 and 60 DAS	33.21	159400	105260	2.95	46.99
T_6: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	34.97	167872	113382	3.08	47.29
T_7: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	32.65	156720	101630	2.84	47.21
T_8: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	36.32	174328	119768	3.19	47.59
T_9: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	33.13	159000	104010	2.89	47.79
SEm±	1.38	-	-	-	0.61
CD (p=0.05)	3.99	-	-	-	NS

3.3 Nutrient analysis and efficiency indices

At the end of two cropping cycles, different treatments did not differ significantly among themselves in respect of available N, P, and K content in soil (Table 3). However, higher available N, P and K content in soil were found under the treatments where iron and zinc either soil applied, foliar applied or both (alone or in combination) over RDF, respectively. Significantly higher available Zn (1.28 ppm) content in soil was found under RDF + 25 kg/ha Zinc Sulphate as soil application + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_6) over RDF, RDF + 25 kg/ha Ferrous Sulphate as soil application (T_3) and RDF + 25 kg/ha Ferrous Sulphate as soil application + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_7). Whereas, available Fe (8.74 ppm) content in soil was significantly higher under RDF + 25 kg/ha Ferrous Sulphate as soil application + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS (T_7) over rest of treatments but remained at par with RDF + 25 kg/ha Ferrous Sulphate as soil application + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS (T_9) and RDF + alone soil application of Ferrous Sulphate at the time of sowing (T_3).

A thoughtful perception of the data in Table 3 shows that the highest agronomic efficiency and partial factor productivity (88.7 and 350 kg/kg, respectively) was registered in RDF + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 DAS (T_4) over other nutrient management modules of Zn and Fe nutrition in crop. Foliar application of plant nutrients would greatly reduce the lag time between application and uptake by the plants, which especially helps the plants to alleviate nutrient stress under moisture-stress conditions (Table 3).

Table 3. Effect of zinc and iron nutrition on available nutrient content in soil (initial and at harvest) and efficiency indices

Treatments	Av. N kg/ha	Av. P kg/ha	Av. K kg/ha	Zn content (ppm)	Fe content (ppm)	AE (kg/kg)	PFP (kg/kg)
T_1: RDF	111.18	14.11	179.23	1.01	6.98	-	-
T_2: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing	112.77	14.67	179.18	1.17	7.03	26.5	131
T_3: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing	111.60	14.47	179.75	1.11	8.64	15.2	120
T_4: T1 + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 days after sowing (DAS)	113.93	14.94	179.58	1.17	7.07	88.7	350
T_5: T1 + Foliar spray of 0.5% Ferrous Sulphate solution at 30 and 60 DAS	113.43	14.70	179.52	1.12	7.84	79.1	341
T_6: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	115.06	15.08	180.17	1.28	7.10	32.6	120
T_7: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	114.53	15.11	179.87	1.12	8.74	23.4	111

T_8: T1 + 25 kg/ha Zinc Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Ferrous Sulphate solution at 45 DAS	116.11	14.95	181.41	1.26	7.85	31.6	106
T_9: T1 + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing + Foliar spray of 0.5% Zinc Sulphate solution at 45 DAS	115.43	14.82	181.11	1.18	8.69	19.9	95
Initial soil fertility	106.40	11.80	136.70	0.53	3.38	-	-
SEm±	1.55	0.56	1.82	0.05	0.27	-	-
CD (p=0.05)	NS	NS	NS	0.14	0.82	-	-

4. Discussion

Among the different treatments, it was showed that zinc and iron either soil applied, foliar applied or both (alone or in combination) resulted in an increase in yield attributes and yield of castor. Treatment where 25 kg/ha Zinc Sulphate soil applied followed by foliar spray of 0.5% Ferrous Sulphate solution at 45 days after sowing recorded significantly higher seed yield in comparison to RDF and RDF + 25 kg/ha Ferrous Sulphate as soil application at the time of sowing. The increase in plant height may be due to better nutrient uptake by the plant. This enhanced uptake likely facilitated optimal growth of plant structures and metabolic processes like photosynthesis, resulting in maximum accumulation and movement of photosynthates to the economic parts. This might be due to ample supply of nitrogen which might have increased protoplasmic constituents, accelerated cell division and elongation processes, and consequently resulted in more leaves. This can be linked to increased source and sink strength [13]. The above observations on yield parameters are corroborated by the findings of [12] and [3].

Higher yield in castor with high fertilizer input was due to readily available plant nutrients leading to greater photosynthetic activity in comparison with low doses of fertilizers. The final economical yield depends on yield-attributing traits. Especially, castor being the crop attains multiple harvest, yield attributes of each harvest contribute to cumulative yield. [19] and [17] collectively demonstrates a favorable response to the application of Zn and S in castor. Combined application of conventional fertilizers along with foliar spray of fertilizers delivered adequate nutrients and resulted in increased yield, which fetched higher net return. [1] also reported that maximum gross return, net return and B: C ratio of sorghum was obtained in plots where foliar spray of 0.5% $ZnSO_4$ at two stages (25 and 45 DAS) was done along with RDF. More and less similar results due to foliar spray of potassium nitrate have amply been documented by [20]. [2] also corroborated these findings. Similar results have been reported by Kumar *et al.* [12].

Different treatments did not differ significantly among themselves in respect of available N, P, and K content in soil. However, higher available N, P and K content in soil were found under the treatments where iron and zinc either soil applied, foliar applied or both over RDF, respectively. Increased soil fertility and micro nutrient availability due to application of organic amendments was also reported by [18]. Agronomic efficiency is a short-term indicator of the impact of applied nutrients on crop productivity. It essentially indicates the grain yield produced per unit quantity of fertilizer material used [4, 5]. Several studies conducted across the globe have demonstrated that a small quantity of nutrients (NPK) applied by foliar spraying increases yield significantly in many field crops [17].

5. Conclusion

In conclusion, the application of Zinc Sulphate and Ferrous Sulphate enhances the productivity of castor. Castor fertilized with Zn and Fe either soil applied, foliar applied or both (alone or in combination) imparts balanced nutrition in castor over the existing recommendation of 120:60:30 kg N, P_2O_5, K_2O per ha. Application of RDF + 25 kg/ha Zinc Sulphate (21% zinc) as soil application + Foliar spray of 0.5% Ferrous Sulphate (19% iron) solution at 45 DAS produced higher seed yield (38.9%), net return (65.6%), and B:C ratio (35.2%) over RDF. This study also showed higher agronomic efficiency and partial factor productivity with RDF + Foliar spray of 0.5% Zinc Sulphate solution at 30 and 60 DAS. The outcome of this study indicated that balanced nutrition plays a key role in the overall excellence of castor in terms of productivity and profitability.

6. Declaration of competing interest

The author declares that they have no conflict of interest.

7. Acknowledgement

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